THE RF POWER SYSTEM FOR RFQ-INJECTOR OF LINAC-20

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Abstract

In the frame of the NICA project the electrostatic injector of LU-20 is replaced by a RFQ accelerator, which has been developed in ITEP. The construction of 400 kW 145 MHz RF power system for RFQ-injector are described. Parameters and test results of the RF power system operated on the resistive load and on RFQ during ion beam acceleration are presented.

INTRODUCTION

In the framework of the NICA project the modernization of injection line is realized. As a result of upgrading the 700 kV electrostatic injector of the DTL LU-20 was replaced by an RFQ. It enables to decrease the potential at the ion source high voltage platform to 150 kV and as result to deliver on it the 35 kW electric power needed for the polarized ion sources operation [1].

The RFQ accelerator, RF power system and low-level RF system were developed in ITEP. The oscillating tube specially developed for application in accelerator technology is used in the RF amplification system [2].

The RF system of the existing linear accelerator LU-20 operates in self-exciting oscillation mode. This requires the dynamic phase synchronization between RFQ and DTL cavities. The RFQ cavity works at the same frequency as DTL and the stability of phase difference between the oscillations in these two cavities has to be kept within tolerance of one degree. The synchronization is provided by a high performance FPGA-based digital Low-level RF system (LLRF).

DESCRIPTION OF RF SYSTEM

RFQ is driven by an RF power system consisting of a solid-state amplifier (SSA), four-stage preamplifier and the final stage based on the high-power water-cooled GI-27AM tube. Block diagram of the RF system is presented in Figure 1.

The RF signal is generated by master oscillator. The SSA amplifies the 10 mW output signal from the master oscillator to a level of 150 W. To protect the SSA, the ferrite circulator with low insertion losses is used at its output. The preamplifier consists of four units with GI-39B triodes, RF power splitter and combiner. It provides the RF power up to 50 kW at the input of the last stage.

The resonator uses two identical RF coupling loops (Figure 2) installed symmetrically in the middle section of the RFQ. The area of loops is about 870mm^2. The non-compensated inductance of couplers leads to a resonant frequency decrease by 33kHz. Fine adjustment of the coupler input impedance is carried out by loop rotation against its axis.

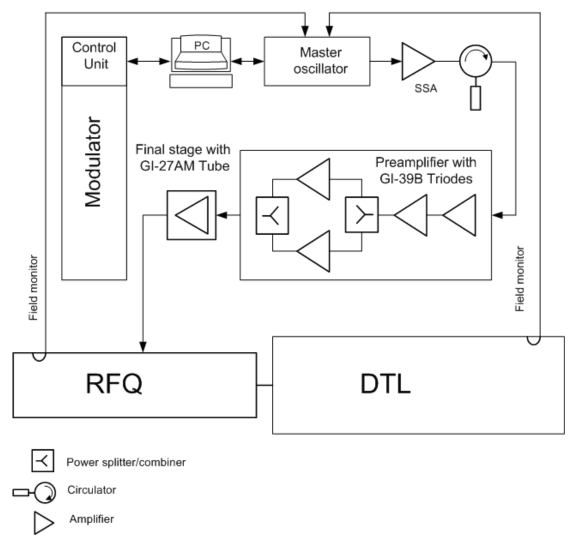

Figure 1: Block-diagram of RF system. PC-computer, SSA–solid state amplifier, RFQ- accelerator, DTL- linear accelerator LU-20.

In the final stage of RF amplifier a powerful generator tube GI- 27AM is used. To obtain the required output power, the tube the power of about 50 kW is needed at the input circuit of. The single unit with GI-39B was tested to define the output power achievable at the DTL frequency 145.2 MHz with pulse length of 150 µs. It was demonstrated that the single lamp can produce power up to 30-35 kW for routine operation.

Also it was found that the output power of two GI-39B connected in parallel get 50 kW which can be transmitted to the input circuit of GI-27AM tube.

A lay-out of the final unit based on the GI-27AM triode is shown in Figure 3. Detailed design of the generator is described in [3].

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Figure 2: RF coupler.

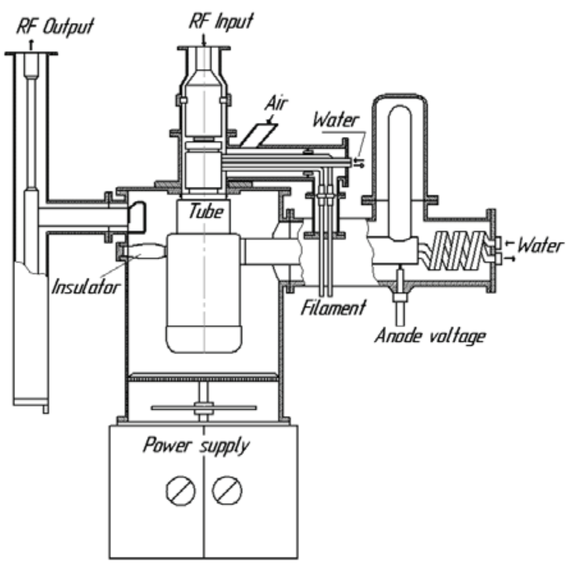

Figure 3: Design of the final stage.

MODULATOR

A high-power voltage modulator was designed to supply the anode of GI-27AM triode. The block diagram of the modulator is shown in Figure 4. A high-voltage power supply HCP700-6500 sets the voltage of the pulse-forming network in the range from hundreds volts to 6,5 kV with accuracy of 0,1%. A bank of 10 thyristor TB -143 -400- 12 in series forms a high voltage switch.

Control of modulator is carried out both in local and remote mode by programmable logic controller via Ethernet.

All components of the modulator are placed in a metallic cabinet with dimensions of 1600 × 1800 × 600 cm. The main obtained modulator parameters are given in Table 1.

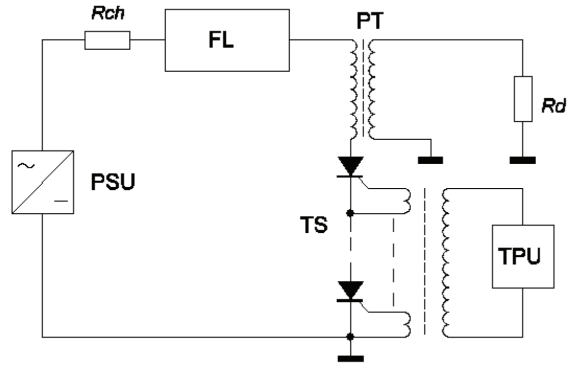

Figure 4: Block diagram of modulator. PSU - high-voltage power supply unit, FL - forming line, PT- pulse transformer, Rch- charging resistor, Rd- dummy load, TPU – trigger-pulse unit.

Table 1: Parameters of Modulator

Pulse power	800 кW
Variation ranging of output voltage amplitude	0-18 kV
Pulse duration by base	150 µs
Amplitude pulse duration	70 µs
Pulse top drop	<1,5%
Amplitude instability	< 1%
Pulse repetition frequency	1Hz
Supply voltage	220V±5%
Power consumption	2 кW

RESALTS

Two methods were used to measure the RF power at RF units. In the first method, the absorbed power meter was used. It implements the method of peak voltmeter [4].

In the second method, RF power was directed to the equal load. The pick voltmeter measured the signal from directional coupler installed at the load. The difference in the power measured by two methods is within the error of the instrument. Output power of the final stage during operation on dummy load is equal to 430 kW at an efficiency of 65%.The main parameters obtained for RF system are given in Table 2.

Table 2. Main Parameters of RF System

Operating frequency	145,2 MHz
Pulse length	150 µs
Pulse repetition rate	1p/sec
Peak output power	430 kW
Peak output power of preamplifier	50kW
Anode voltage on the final stage	18kV

Cold measurements of RFQ resonator results:

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- unloaded quality factor Qo=5200,
- loaded quality factor Ql=2550,
- operational resonant frequency f=145,2 MHz.
- The amplitude of the fields in the four chambers of the RFQ resonator differ each other by less 2%.

First test of RFQ with high power were carried out in ITEP. High power test was started under of $5{,}6{\cdot}10^{-5}$ Pa. The level of input power was measured by the reflectometers installed at the output terminal loops of the final unit. The power required for the acceleration of ions with Z/M = 0.3 was achieved in one month of commissioning.

The beam test was carried in JINR in Dubna. The RFQ and RF power supply were moved and installed in the experimental hall of LU-20 (Figure 5 and 6). In one week after the start of pumping the designed RF power was delivered to the RFQ. The measured result of the RF power into RFQ versus charging voltage on modulator is given in Figure 7.

The successful commissioning of the RFQ and RF power supply was carried out with deuterium and C^{+} ion beams.

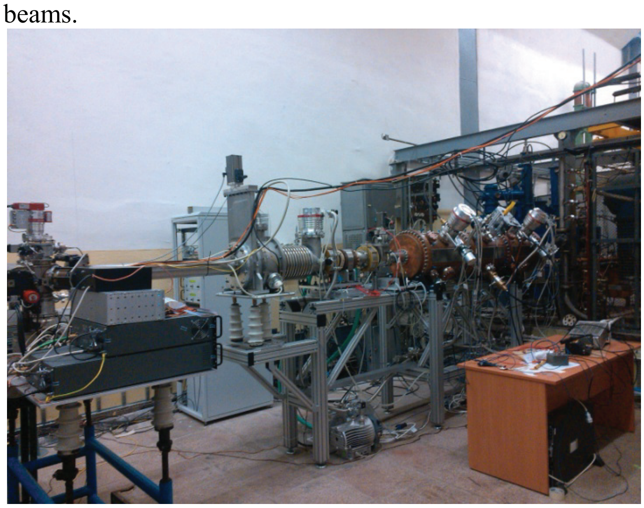

Figure 5: RFQ in experimental hall for commissioning.

Figure 6: RF power system mounted in JINR.

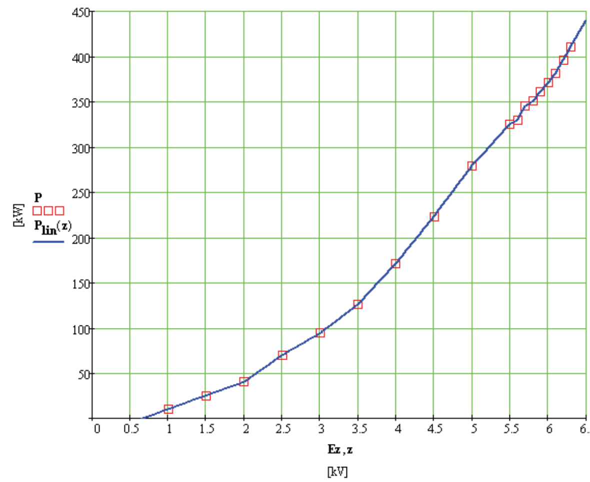

Figure 7: The RF power delivered into RFQ (P) versus charging voltage of modulator (Ez)

CONCLUSION

The RF power system developed in ITEP for new RFQ provided the successful acceleration of C^{4+} ion beam during commissioning. The required power was delivered to RFQ in one week after all system (both RFQ and RF power) was moved to JINR in Dubna and assembled at the test point (Figure 6). The successful result of RFQ test enables the replacement of old electrostatic injector by the RFQ and its commissioning with deuterium ion beam as a part of Nuclotron facility. The test turn of Nuclotron with RFQ was carried out successfully on May-June 2016.

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